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THE IMPACT OF MAN ON THE TROPICAL ENVIRONMENT

Water control and impoundments
The aquatic side

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SUMMARY

Man's impact in water control and impoundment is great and increasing rapidly in tropical countries. Though sometimes underground water is extensively pumped, most water control schemes start with a barrier impounding flowing water; tending towards an increase in area of standing water on the earth, usually richer in nutrients than the flowing water before impoundment. New waters are colonised rapidly by aquatic organisms, plants forming a succession towards climax species. Explosive reproduction of organisms, including an exotic species in Kariba, is discussed. Tropical fish usually prefer the new standing to old running water conditions, resulting in numerical increases though the composition of species may vary. Increases are usually observable also in other waterloving animals. Water control often causes great increases in the human populations that adjoining areas can support, leading to extensive environmental changes. Deleterious changes generally are observable where so much water has been impounded that the rainfall or catchment area is inadequate to spill water over the barriers to the system below; consequences are often extremely serious, causing destruction of life and permanent damage to land and water resources. Stocking with foreign fish has sometimes had undesirable consequences and even eliminated endemic species. Water control schemes, especially for industry or human sanitation, frequently pollute natural waters if not properly planned. The need for forethought and adequate planning of water schemes, especially regarding the degree of permissable impoundment, is stressed. Attention is drawn to the fact that, while human populations continue to expand exponentially, manipulating water for immediate human use must take precedence over all other considerations, to the detriment of all other life and ultimately to humans themselves.

RÉSUMÉ

L'impact de l'homme sur le contrôle et le captage des eaux est d'envergure et s'accroît rapidement dans les pays tropicaux. Bien que parfois les eaux souter-

raines soient dans une très grande mesure pompées, la plupart des projets de contrôle des eaux commencent par l'endiguement de l'eau courante d'où la tendance à une augmentation de la superficie des eaux stagnantes à la surface de la terre, plus riches en général en éléments nutritifs que l'eau courante avant l'endiguement. Les nouvelles eaux se peuplent rapidement d'organismes et de plantes aquatiques qui évoluent en fonction des facteurs du milieu vers des espèces particulières. La reproduction explosive des organismes, notamment d'une espèce exotique à Kariba, est une question débattue. Les poissons tropicaux préfèrent en général les nouvelles conditions à celles de l'ancienne eau courante, de sorte que leur nombre augmente, bien que la composition des espèces puisse varier, de même que celui d'autres animaux qui ont une prédilection pour l'eau. La domestication des eaux provoque souvent de fortes augmentations de la population humaine, ce qui modifie considérablement les lieux. Des changements nuisibles s'observent en général lorsque la quantité d'eau endiguée est telle que l'aire de réception des pluies ou de captage ne permet pas à l'eau de se déverser par-dessus la digue et de s'écouler sur le plan situé en aval; les conséquences en sont parfois extrêmement graves, causant la mort et des dégâts permanents aux ressources de l'eau et du sol. L'apport de poissons étrangers a eu parfois des résultats regrettables et a même éliminé certaines espèces endémiques. Les projets de contrôle des eaux, en particulier pour l'industrie ou l'hygiène domestique, ont fréquemment abouti à la pollution des eaux naturelles quand ils n'étaient pas bien préparés. La nécessité d'être prévoyant et de mettre convenablement au point les projets de contrôle des eaux, en particulier en ce qui concerne le degré de captage permissible, est mise en relief. L'attention est attirée sur le fait que tant que les populations humaines continueront de s'étendre exponentiellement, l'approvisionnement pour l'usage immédiat de l'homme doit primer toute autre considération au détriment de toute autre vie et ultérieurement des êtres humains eux-mêmes.

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Man's impact on the aquatic side

Water, when it falls to earth, obeys the law of gravity and finds its way eventually to the lowest possible level, usually the sea. Only occasionally is this downward movement halted under natural conditions, when natural conformations of the earth's surface allow impoundment in lakes and ponds. The advantage to the species of arresting the perpetual downward flow of somewhat more of this water by artificially impounding it has occurred to rather few animals, notably the beaver, but most markedly to Man. Man has carried out this practice from the earliest times, and, like so many of his activities, at an ever-increasing and latterly almost breathtakingly rapid tempo, until at the present time his impact on the earth in regard to the control and impoundment of water is tremendous. I examine here briefly some of the effects of this on the aquatic side of the tropical environment; even thus restricted the subject can only be treated generally.

In some tropical areas underground water is extensively pumped, but from the most primitive to the most advanced, water control schemes usually start with a barrier to the flow or downward movement of water. Barriers are variously called dams, weirs, bunds, etc. Referring to all generically as dams, it can be seen that all have a number of factors in common. All halt the flow, turning running into stagnant water, and all increase to a greater or lesser extent the amount and area of surface water on the earth. Physically this water is commonly richer in dissolved nutrients than the original flowing water, especially in the early stages of impoundment, because of the leaching effect from previously uncovered soils, and later the silt carried by inflowing streams. These changes in the environment come into effect immediately the dam is built; ecologically speaking they are physical changes and they at once initiate a series of biological changes in the flora and fauna of the environment.

The early major biological changes are the destruction of the original dry-land flora and fauna within the water-covered area of the dam's basin. Destruction of the flora is complete; that of the fauna is very large but varies to some extent with the type and variety of the fauna present and the extent of the area inundated. Sessile, sedentary and slow-moving animals such as earthworms, many insects and other arthropods, small fossorial mammals, etc., are destroyed wholesale, but many flying, swiftermoving or larger animals are able to escape alive or, if the dam is very large and sufficient interest taken in their plight, as in the case of the Kariba Dam (1), are able to be artificially saved from drowning or starvation. This paper is too short to enlarge upon this interesting aspect of Man's impact on the earth; I can only summarize by saying that whether through death by drowning or starvation, or removal by their own efforts or rescue, the dryland life is entirely eradicated. No viable habitat remains barren for long, however, and this life is instantly replaced in progressive stages, by an aquatic flora and fauna.

Before the popular press made the world familiar with the " population explosion " or too-rapid growth of our own species, Elton (2) had studied and defined ecological explosions; the enormous increase in numbers of a living organism because forces which previously held it in check no longer apply, commonly through artificial removal of an organism to a foreign habitat, so that factors which kept it in check in its old home no longer are there in the new, or secondly because of the artificial increase in size of its own environment. Such ecological explosions occur when man impounds water (3), and are a major consequence of his activities in this direction. In tropical Africa I have been fortunate to have had to do with some very typical examples, but the main sequence of events in all tropical countries can be described in general terms.

Replacement of the old dry-land by the new aquatic flora follows a usual botanical succession of plant life from the pioneering to the climax species. After inundation by a dam the flora is almost entirely of algae, mainly planktonic, and these very rapidly build up to enormous numbers because of the comparative richness of the new waters due to leaching of nutrient salts from a previously uncovered substrate. So great, in many cases, is the first bloom of planktonic algae that several undesirable side effects may initially be produced, such as the death by poisoning of animals which drink the water (4), and pollution of water (and the surrounding air) by great banks of algae washed to the shore by storms or high winds. At the same time there is an almost equally great increase in the

numbers of zooplanktonic animals, particularly crustacea (5). Of higher plants the initial invaders of new waters are mainly floating aquatics such as the Water Cabbage (*Pistia stratiotes*), the Water Hyacinth (*Eichornia crassipes*) and the Water Fern (*Salvinia auriculata*). Quite soon however other secondary growths appear and the botanical succession has begun. Here I divert briefly from the general to consider the case of the Kariba Dam and *Salvinia*, a fine example of an ecological explosion caused by the invasion of a new area by a plant artificially introduced by Man.

Salvinia auriculata is endemic to South America and was first recorded from the Upper Zambezi river, Africa, about fifteen years ago. An individual plant is decorative, much favoured by those who keep small tropical fish as a hobby and is widely sold for this purpose. It was almost certainly an aquarist, perhaps discarding an apparently moribund plant from his aquarium at Livingstone on the Upper Zambezi, who introduced it to the river system. The plants which later exploded on Lake Kariba all exhibited abnormal ploidy and are apparently unable to reproduce sexually (6), evidence that they are descended from an aquarist dealer's stock. Upstream migration was naturally slow; the plant while abundant for fifty miles or so above Livingstone had not by 1962 reached Sesheke, but the closure of the Kariba dam in December 1958 created an enormous and suitable environment downstream which resulted in a gigantic multiplication of the plant, covering, in 1961, a minimum of 150 square miles of water (7), aided, of course, by the lack of natural controls on this exotic species. Measures have been taken to evaluate feasibility and costs of poisoning or reducing it by mechanical means, while biological control measures, the introduction of animals to eat it, ranging from the introduction of manatees through coypus, to snails, weevils and moths from its ancestral home, have been proposed but not as yet implemented. As the dam grew in size during the filling years from 1959 to the present, the plant's preference for sheltered bays and estuaries and its dislike of open waters and wave-beaten shores has become apparent, and plant succession on it has been going on. An early successor which grows on the *Salvinia* mat is the annual sedge *Scirpus cubensis*, itself used as a growing base by a variety of other plants. There is little doubt but that, left to itself, swamp terrain would form in sheltered areas of Kariba, with *Salvinia* present on pools and other water surfaces but with much of the area covered with plants forming the climax of the succession such as the Papyrus (*Cyperus papyrus*).

A very important consequence of impoundment is its effect on the fish of the river across which the barrier has been erected. These fish are fluviatile forms adapted to life where there are fluctuations in quantity, rate of flow and physical attributes of the water according to the seasons, but it seems broadly true that in the tropical environment the bulk of the indigenous fish species present prefer the stagnant to the flowing water conditions, such important running-water forms as salmonids, for example, being largely absent. Thus most species in tropical waters use sheltered and semi-stagnant conditions such as ox-bows, flooded tributaries, swamps and flood-plains to spawn, reproduce themselves and have their being as far as possible (8). The creation of a dam enlarges and multiplies such favourable environments together with increased food supplies and cover from predators, with the result that, again, we have initially a very rapid expansion in numbers of most of the fish present, compared with what

used to be the case before (9). Torrential or entirely flow-loving species, which are generally in a minority in tropical fish aggregations, may either disappear entirely within the dam or their range restricted to small areas at river inflows where the old conditions still apply, but in general most species of the old stream increase greatly in numbers, though the composition of the new fauna may vary in comparison with that of the old.

In other animals a similar general trend takes place of an increase in those which an aquatic environment favours, such as hippopotami, monitors, crocodiles, certain wild-fowl and other birds, aquatic snails and insects, and so on. Water-frequenting antelope such as puku, water-buck and reedbuck may increase. Sometimes increases are in unexpected directions, such as the death of a large number of trees, partly still emergent from the water, leading to great increases in the numbers of wood-boring beetles. Indirectly increases may be caused by the availability of water for drinking in areas where it was not previously present during dry periods, so that dams for this purpose are an important feature of wild-life management programmes. Some dams have indirect effects on water-courses below them, by regulating the flow of large rivers or heightening the water table of arid areas, resulting in springs or more luxurious vegetation to the benefit of animals often a considerable distance below the barrier.

Activities in impounding water lead almost inevitably to changes occurring in the aquatic fauna, a most important impact of Man on the tropical environment. The barrier which impounds the water is often a barrier also to the upstream migration of fish. This can be avoided by the creation of a fish ladder when the dam is built, but often the cost of providing such a ladder is reckoned to be too great, or the migratory fish considered to be too commercially unimportant for the facility to be provided. In tropical Africa, common victims are the several species of freshwater eel, which abound in many eastward-flowing rivers and go to the sea to spawn, the young returning to points often many hundreds of miles from the coast. A large dam on such a river, without a fish ladder, means that the eel population is eliminated from the fauna upstream of the dam. Dams contain a riverine fauna which, though multiplying abundantly nevertheless occupy a habitat similar to that which prevailed in the old river, so that in larger dams there are several ecological niches, particularly in relation to the open-water (pelagic) habitat, which remain unfilled by the indigenous fauna. For this reason, and also because this or that fish is considered to be a desirable one to have in the new dam for one reason or another, there usually is an impressive list of proposed introductions of foreign fish, some of which are carried out with varying primary and secondary effects on the local fauna (10). With regard to introductions from other zoogeographical regions, while the fish fauna of the African Continent as a whole is large and varied, it seems a peculiar quirk of human nature that many zoologists and others who would not for a moment contemplate augmenting the African terrestrial fauna with the bear, the moose, the panda, the orang-outang, the marmot or the mule deer have imported the large-mouth bass, the spotted bass, sunfish, goldfish, perch, tench and carp. The carp is a particularly tricky importation as though it can be useful if carefully bred and farmed in captivity it has been known to cause immense damage when allowed or escapes into a foreign water system (11). Fortunately, however, the carp seems seldom able to breed prolifically in the wild state in tropical waters.

The creation of impoundments are in themselves a potent factor in their influence on the increase of human populations. By allowing new land to be irrigated, more domestic livestock to graze or water, more food is made available leading to more humans inhabiting the area and making their mark on it in a multiplicity of ways not directly connected with the impoundment. Where the population is very heavy, and water control much practised, the entire physical surface of the environment can be changed beyond recognition. This has happened in parts of the Far East where entire hillsides, let alone the valleys below, have been terraced into rice paddies and fish ponds (12), so far has water control been taken, so that the original vegetation and even the smaller members of the fauna have all but disappeared, being replaced by aquatic wild and domesticated forms over very large areas. Parasitic organisms and their intermediate hosts such as snails and mosquitoes may here increase enormously in comparison with their numbers in previous decades. The spread of the diseases schistosomiasis and fascioliasis have for example been made more rapid by the increase in man-made impoundments and water control artefacts such as small farm dams or ponds or irrigation furrows, these being often a better environment for aquatic molluscs than the streams from which they derive (13).

Having discussed various aspects of increases caused directly or indirectly by impoundments and water control, we may consider some of the decreases in life caused by Man's activity in this direction. The extinction of any species is a tragedy, and Man is, as with terrestrial forms, only too likely to bring about reduction in numbers and in some cases extinction of aquatic species. Fishing is, by and large, a form of hunting rather than of agriculture because, except in pond culture, the fisherman still, like the hunter, reaps what he does not sow, so that phrases such as " the harvest of the sea " are still much more figurative than accurate. However, unlike the hunting of terrestrial animals, fishing as such does not carry with it the danger that, if unmanaged, numbers of a species can fall to dangerously low levels. Over-fishing can quite easily bring about a situation wherein it is no longer economical to fish for a species, and can even so decrease the numbers of a fish that it is not even worth the while of a food-seeker to pursue it any more in its watery and obscure environment, but even in this unusually extreme case some will be left which will reproduce and pull the numbers up again.

Extinction of a fish population comes not because of attacks on it, but indirectly, because of attacks on its environment, and this can be a major effect of Man's impoundment and water control schemes. The over-use of water in dryer areas, for example for irrigation, coupled with the over-use of land causing overgrazing, soil erosion, and subsequent silting resulting from lack of soil cover, are all examples where what was not long ago a perennial water, a habitat for fish, may dry or be silted up, destroying the life that was present. Bad land use can and often does lower the underground water table; this may have a subtle effect even on the fauna of large rivers, because their fish migrate into small streams to spawn, such streams being kept alive by springs which, when they dry up through the fall in the water table, destroy a habitat used in the life history (14). Even more indirect are cases where habitats are destroyed by the encroachment of sea-water in coastal rivers, due to impoundments higher in the river having several adverse effects, firstly too many dams holding back too much fresh water

thus allowing sea water to diffuse upstream, destroying the fresh-water life, secondly silting of the lower reaches caused by either the many impoundments not allowing sufficient flood to scour the area below or by erosion from bad land use of areas irrigated from impoundments causing unprecedentedly severe silting of rivers. Many examples are well known; I cite here a less known but very typical case from the sub-tropical Bushman's River in South Africa. As more and more dams were built across the river less and less water came down and the river has not flooded since 1953, not even during the especially good rains of March and April 1963. For at least fifty miles above the ebb-and-flow (the highest point of the tidal river) the water has become very saline and freshwater fish have disappeared. From the ebb-and-flow to the mouth, about twenty-one miles of river, the water is completely saline with marine life (as against the old characteristic estuarine life) all the way up now. Due to the lack of scouring the mouth and river a few miles inland is silting up very badly. Such is the sad fate of many Southern African estuaries; sand brought in by spring tides and not being scoured out due to so many conservation works in the catchment above is an additional ruinous factor (15). For brevity I mention only the well-known case of the destruction of the large Lake St. Lucia in Zululand, ruined by incredibly huge siltation from badly managed land used in sugar growing during the last few decades and lately by dams impounding the inflowing rivers which will make the lake completely saline.

The wide-spread habit of stocking with non-endemic and often completely foreign fish has been mentioned. Such fish have often been known to exterminate or greatly reduce local species which cannot compete with the introduced species (10). A recent example is that of the endemic fish *Labeo quathlambae* from the Umkomazana River, Natal, which was described in 1938 (16), but which has since disappeared from the river, so that this unique species can no longer be found (17). I am informed that the reason is that the Umkomazana river has been stocked with rainbow trout.

I have deliberately, in this short paper, avoided mention as yet of the problem of water pollution and the destruction of fish and other aquatic life because of it. No account, however brief, on the present subject is nevertheless complete without mentioning that water control schemes are in very many cases for industrial purposes (the use of water for factories is enormous and increasing daily) and for the disposal of human sewage. The subject is very large; here I can only draw attention to one or two facts to indicate the importance of the effect of water pollution on the natural environment. It tends to increase as a country is industrialized; many tropical countries are not as yet sufficiently " developed " industrially for the problem to assume the proportions that it does elsewhere, at the present time. Sewage disposal from high human populations (in England and Wales, for example, it was estimated that in 1957 the human population produced 1,500 million gallons of sewage per day, of which rather more than three-quarters, together with a similar proportion of industrial wastes, are discharged into inland waters (18)) is however a universal problem, though mitigated somewhat in many highly populated tropical countries by the use of human sewage as fertiliser. Too often however rivers, even in the most " developed " countries, are still being used as main drains. But much is now being done to deal with the problem after years of neglect. To quote Hynes (18): " we have

just entered an age where town-planners and borough engineers really worry about pollution, and industrialists consider the disposal of effluents in deciding where to site new factories" (p. 7). What is true in temperate-zone countries should be the case also in the tropics; all countries with advanced governments should take the problem of pollution seriously, and have adequate laws on the subject.

In conclusion, we might speculate as to what the future holds, where Man's impact here is going to take us. These activities are increasing at an exponential rate; we are nowhere near even a slowing down of Man's manipulation of water. More and more schemes, ranging from huge international efforts to impound the earth's largest rivers to the peasant's wife hoeing another bund to wet the paddy a little more, are being undertaken. Each in its own way alters the environment from its previous natural state. We have seen that many dams are valuable to aquatic fauna in allowing a larger environment for them, an increase in their numbers, a greater chance of survival, better opportunities for managing and using them; these are generally where the rainfall is high, the river impounded is large or the catchment enormous. They are, in other words, where the water impounded can be spared. But very often the water cannot be spared below, and a variety of ill effects arise from this, or mismanagement of the land results through overgrazing or careless irrigation, or the water controlled is contaminated and discharged to pollute natural waters, and here, only too often, Man's impact is deleterious.

Consider the appalling suddenness with which this can happen. The examples cited above are of very recent occurrence, within half a lifetime or less; in general the earth's surface is vastly changed from what is was when our grandfathers were born, having remained in balance unchanged for millennia previously. And the impact is increasing, not decreasing. Often, it would seem, Man has been tempted by the excellence of modern equipment which makes the execution of schemes, access roads to them, etc., easier than was the case a few decades ago, by political expediency, by a real or imagined need to justify a post or even government department, by the real or fancied advantages of exotic animals or plants, by the general economic and social pressures of our times and above all, by fears of famine, etc., inherent in the fantastic rise in human populations during the recent past, to enter into some schemes of water control and impoundment too quickly, without adequate thought and long-term planning.

There has in recent years been an increasing awareness of the need for planned management, of the need for Man to think before he acts, to conserve and husband our renewable natural resources adequately. The standpoint of the freshwater biologist can only emphasize the urgency of this need. In particular, the degree of permissable impoundment of any water system should be carefully studied and rigorously enforced, having regard to the need of the country as a whole and not those of vested or sectional interests. But while much must be done here to ensure proper land use and conservation, the root, long-term cause, engendering perhaps all of the pressures mentioned above, is the inordinately large rise in the numbers of our own species within recent years, and the promise of future increase in the rate of expansion. Having taken 200,000 years to reach a world human population of 2,800 million people, most of the increase having taken place within the last 100 years or less, it will now take only another 30 years to

add another 2,000 million to it (19). Increases at this rate tend to nullify the best efforts of all conservationists; there are in fact too many people in the world, as a result of which all other life, and in the not far distant future the people themselves, must be adversely affected. In the field of management and conservation of water, as in so many others, this remains the fundamental and most pressing problem of our time.

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